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Penetration Depths of Conducted Electrical Weapon Probes Into Human Skull Phantoms

Stephan Andreas Bolliger, MD, Silvan Gort,† Beat Kaelin,‡ Vera Barrera, MD,* Michael Josef Thali, MD,* and Rosa Maria Martinez, MD**

Abstract: Occasional case reports have described isolated cases of conducted electrical weapon (CEW) probes piercing the human skull. In an experimental setting, we examined whether these cases were just unfortunate incidents, how deeply such probes can pierce the skull, and whether firing distance and CEW probe type play a role in the skull-piercing capability.

We fired 5 different CEW cartridges (XP 10.6 m, XP 7.6 m, smart 10.6 m, smart 7.6 m, and smart probe 7.6 m) from 4 different distances (0.5, 1, 2, and 4 m) at head phantoms made of either 5- or 7-mm-thick polyurethane spheres covered with a thin layer of gelatine and buckskin. The piercing depths were recorded by computed tomographic scanning.

All tested cartridges managed to pierce the head phantoms. Piercing depths of up to 6.6 mm in the 5-mm heads and depths of almost 5 mm in the 7-mm heads were recorded. Deepest piercing depths were attained with firing distances of 2 m or less.

Our results showed that all tested CEW probes are capable of piercing the skull and that shorter firing distances tend to lead to deeper piercing depths.

Key Words: CEW, TASER, skull piercing, cerebral damage, synthetic skull model

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Conducted electrical weapons (CEWs) such as the X2 and the X26 from TASER International Inc. (Scottsdale, Ariz) have been increasingly introduced to police forces worldwide.

Most CEW devices used in Central and Western Europe are either X26 or the newer X2 TASER guns. These weapons are loaded with cartridges containing 2 probes on a long wire, which are propelled by nitrogen gas. There are several cartridges in use; the main difference is that the flight angle of the 2 probes differs between the short-range 7.6-m cartridges and the long-range 10.6-m cartridges and the probe itself. Today, the new "smart" and "smart probe" (SP) containing cartridges are generally used, as the older XP probes are not produced any more.

The possibility of these devices causing death due to fatal cardiac arrhythmias has been discussed controversially in the literature; several authors have argued that CEWs are capable of and have caused death,[1–6] whereas other authors have claimed that the risk of serious injury or death is extremely unlikely after CEW use.[7–10]

Animal experiments have suggested that serious cardiac events due to CEW exposure are—in the worst case—very rare,[11–13] and analysis of the blood after CEW exposition in swine and humans showed no alarming changes to blood chemistry, especially regarding creatinine kinase and acidosis.[14–16]

However, this does not apply to the mechanical dangers CEW can have on humans. Besides the obvious, namely, serious or fatal fall injuries of subjects briefly incapacitated by the CEW charge,[17,18] there is the danger of ignition of highly combustible or explosive fumes by CEW[19,20] and of penetrating ocular injuries.[21–29] These ocular injuries often result in permanent loss of sight due to persisting eye damage or the necessity of enucleation. Kunz et al[30] examined the piercing capacity of the TASER eXtended Range Projectile on ballistic soap and noted penetration depths of up to 4.2 cm. Cadaver testing of the eXtended Range Projectile, which is not produced anymore since 2012, showed no fracturing of the ribs, lung or aortic lacerations, and one instance of abdominal cavity piercing in 43 given shots.[31]

Another, rare CEW-induced injury is cranial penetration by a probe. Le Blanc-Louvry et al,[32] Chandler et al,[33] and Rehman et al[34] all describe frontal bone penetrations of TASER barbs in young men aged 16 to 27 years. In each case, the barbs were subsequently removed without neurologic sequelae, although Rehman et al did report that the victim had a brief period of unconsciousness after sustaining the injury. Le Blanc-Louvry et al described the weapon used as a TASER X26, whereas Chandler et al and Rehman et al simply state that the weapon was a TASER.

The question therefore arises whether these skull penetrations are just unfortunate single incidents or whether CEW probes are generally capable of piercing the human skull, and if so, which CEW probe—the XP or the new SP—is most likely to pierce the skull and how deeply, and whether the firing distance plays a role in the piercing capacity. To answer these questions, we performed the following study on human skull simulants covered with synthetic skin and soft tissue.

MATERIALS AND METHODS

Head Phantoms

According to Moreira-Gonzalez et al,[35] the human skull thickness ranges from 5.3 to 7.5 mm. For this reason, we chose hollow spheres made of polyurethane coated with silicone with 5- and 7-mm wall thickness (PR0112.G: generic sphere, 5 mm; PR0110.G: generic sphere, 7 mm; Synbone AG, Malans, Switzerland) as skull simulants. We decided to use spheres instead of polyurethane sheets, as the curvature, which might influence the stability of the material, was similar to the human forehead, which of course is not the case in a flat sheet. Furthermore, the used polyurethane spheres have proven to be reliable skull models in the past.[36–41] These skull simulants were covered by a 5-mm-thick layer made from 20% wt/wt ordinance gelatin (Type 3 Photographic Grade; GELITA AG, Eberbach, Germany) as described previously[42] as a soft tissue simulant. The synthetic skull and the soft tissue simulant were then wrapped in buckskin (Jumbo-Markt AG, Dietikon, Switzerland), taking great care to present the side facing the shooter without folds.

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From the *Department of Forensic Medicine and Imaging, Zurich Institute of Forensic Medicine, University of Zurich; †SWAT, City Police Zurich; and ‡Firearms Division, Forensic Institute, Zurich, Switzerland.
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Reprints: Stephan Andreas Bolliger, MD, Department of Forensic Medicine and Imaging, Institute of Forensic Medicine, University of Zurich, Winterthurerstrasse 190/52, CH-8057 Zurich, Switzerland.
E-mail: stephan.bolliger@irm.uzh.ch.

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FIGURE 1. Comparison of the older XP probe on the left and the new SP on the right. Note the 14-mm-long tip of the XP probe with only one barb compared with the slightly shorter (11.5 mm) tip of the 2-barbed SP. Figure 1 can be viewed online in color at www.amjforensicmedicine.com.

FIGURE 2. Phantom after being hit by 2 SPs fired from an X2 CEW. After firing, all stuck probes were numbered and left in place for subsequent CT scanning. In this case, the upper probe of shot number 11 was counted. Figure 2 can be viewed online in color at www.amjforensicmedicine.com.

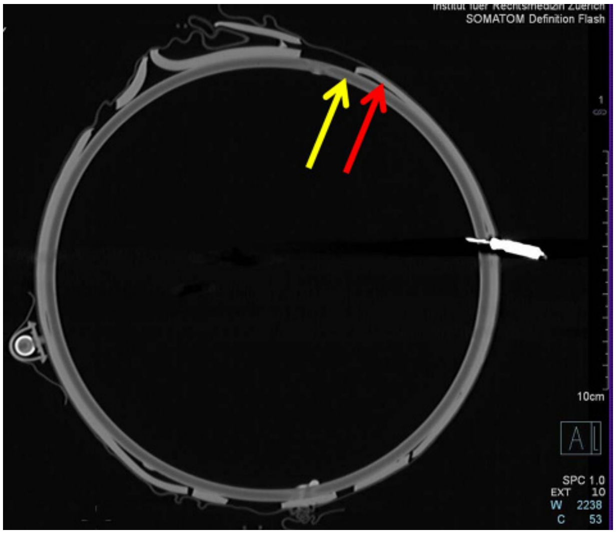

FIGURE 3. Computed tomographic scan of a 5-mm head phantom showing a piercing SP. Note the thin buckskin enveloping the polyurethane sphere (yellow arrow) and the thin gelatin layer (red arrow). The round structure to the left of the image is a nitroglycerin capsule, which was placed on the phantom to facilitate orientation when regarding the CT images. Figure 3 can be viewed online in color at www.amjforensicmedicine.com.

Firing

The head simulants were fired at from a distance of 0.5, 1, 2, and 4 m with an X26 CEW loaded with XP 7.6 m and XP 10.6 m, and an X2 CEW loaded with smart 7.6 m, smart 10.6 m, and SP 7.6 m. Details of the used probes are shown in Figure 1.

Only centrally located hits to the middle portion of the head simulant facing the shooter were counted (Figs. 2, 3). XP 7.6 m and XP 10.6 m were fired twice per distance unit at the 5-mm heads and once at the 7-mm heads, and smart and SPs were fired once per distance unit. Glancing hits were not considered. A total of 48 shots were included. Eight XP 10.6 m probes and 8 XP 7.6 m probes were fired at the 5-mm heads, and 4 of these cartridges were fired at the 5- and 7-mm heads each. Four smart 10.6 m, smart 7.6 m, and SP 7.6 m probes were fired each at 5- and 7-mm heads.

Data Acquisition

All the heads with the probes still stuck then underwent computed tomographic (CT) scanning. Computed tomography was performed with a 128-slice dual-source multidetector row scanner (Somatom Definition Flash; Siemens Healthcare, Erlangen, Germany) at 140 kV using a tube current time product of 1200 mAs, a slice collimation of 0.6 mm, a rotation time of 1 second, and an spiral pitch factor of 0.35 mm. The length of the probe tip within the sphere cavity was then measured.

RESULTS

Piercing Capability

Fired at 5-mm heads, 2 of the 28 probes failed to pierce the skull, namely, 1 XP 7.6 m at 0.5-m distance and 1 XP 10.6 m at 4-m distance. All the probes fired with the smart cartridges pierced the 5-mm skulls. The tip of the XP 7.6 m, which failed to pierce the 5-mm head at 0.5-m firing distance, was bent within the polyurethane wall of the skull; thus, although the entire tip of the probe penetrated the skull, it could not pierce into the cranial cavity. Several of the more deeply penetrating probes, especially the SP 7.6 m, created minuscule polyurethane fragments when piercing the skull.

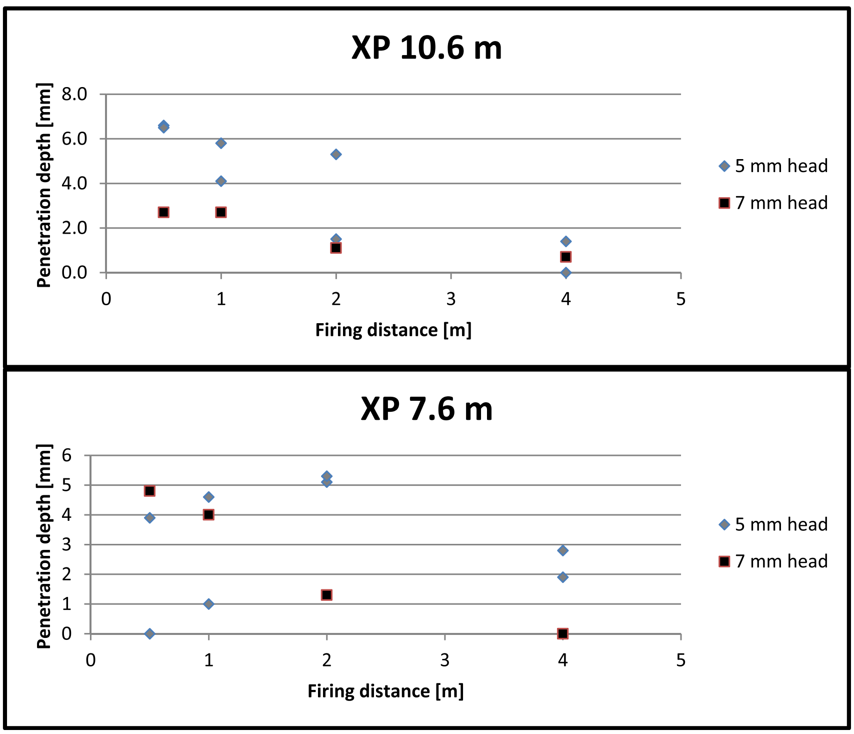

FIGURE 4. Graphs showing the penetration depth compared with the firing distance of X26 CEW ammunition in 5- and 7-mm head phantoms. Figure 4 can be viewed online in color at www.amjforensicmedicine.com.

The 7-mm heads proved to be more piercing resistant: 4 of 20 probes failed to pierce these skulls; 1 smart 7.6 m at 1-m and at 4-m firing distance, 1 smart 10.6 m, 1 SP 7.6 m, and 1 XP 7.6 m could not penetrate the cranial cavity.

Maximum Piercing Depth

The deepest penetration depths of 5-mm heads ranged between 5.1 mm (SP 7.6 m) and 6.6 mm (XP 10.6 m at 0.5-m firing distance; Figs. 4, 5). Seven-millimeter heads, again, prevented very deep piercing; the maximum penetration depth of these heads was—depending on the cartridges used—between 3.9 mm (SP 7.6 m at 2 m) and 4.8 mm (XP 7.6 m at 0.5 m).

Firing Distance Influence on Piercing Depth

Of the 5 cartridges tested on 5-mm heads, 3 pierced most deeply at 2-m firing distance (Table 1), whereas 4 pierced least deeply at 4 m. At 1-m firing distance, 3 of 5 cartridges pierced second-most deeply.

LIMITATIONS

One major point of discussion is the choice of the experimental material, namely, the polyurethane skulls. Although these synthetic skulls, or rather spheres, differ from real skulls in their shape and material, they have been used successfully as simulants for human skulls in numerous experiments in the past.[36–41] In these tests, in which the skulls were compared with real human skulls, the synthetic skulls demonstrated comparable properties with regard to damage in ballistic experiments. These past, validated experiments suggest that the sturdiness of our synthetic skulls is comparable with that of real human skulls and therefore serves as a viable simulant for the penetration of CEW probes. Another aspect this study could not address was whether the probes could have penetrated the dura mater after having pierced the skull.

DISCUSSION

Our results showed that all tested cartridges and probes, namely, the XP 10.6 m, the XP 7.6 m, the smart 10.6 m, the smart 7.6 m, and the SP 7.6 m were capable of piercing the synthetic skull covered with soft tissue and skin simulant.

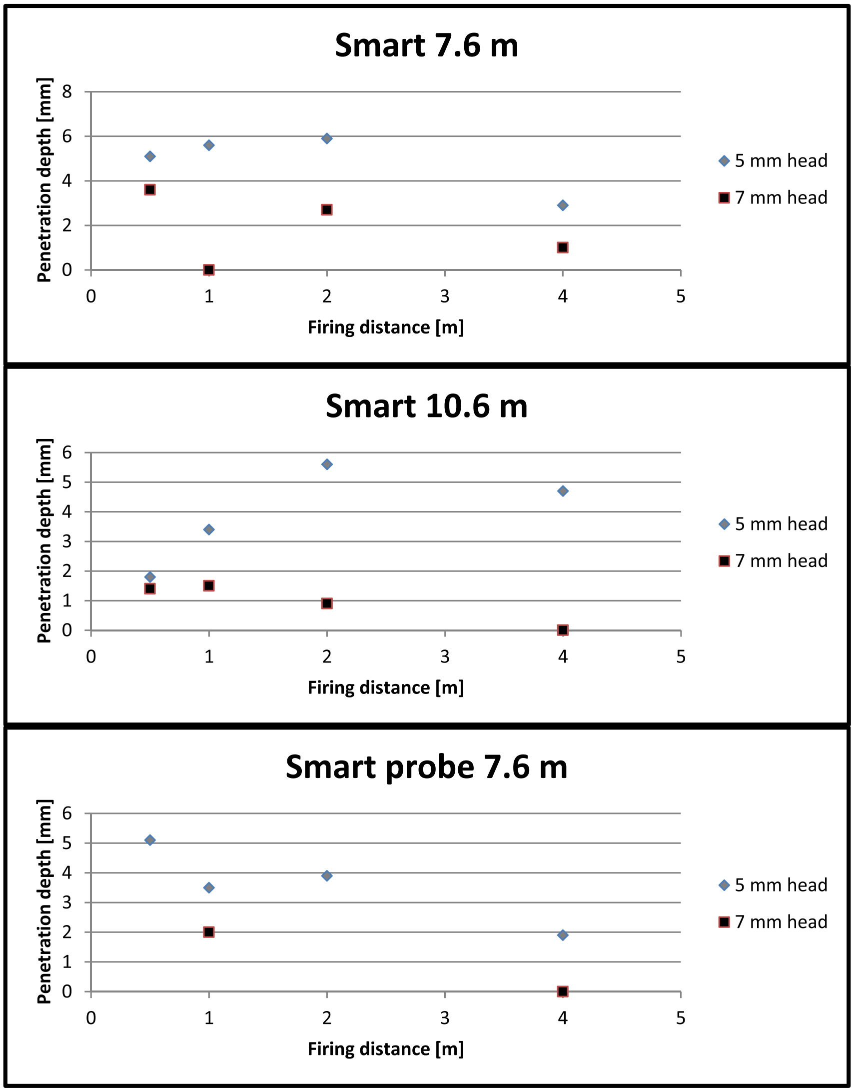

FIGURE 5. Graphs showing the penetration depth compared with the firing distance of X2 CEW ammunition in 5- and 7-mm head phantoms. Figure 5 can be viewed online in color at www.amjforensicmedicine.com.

TABLE 1. Comparison of Firing Distance Versus Ranking of Piercing Depths in 5-mm Heads

	Distance, m				
Rank	XP 10.6 m	XP 7.6 m	Smart 10.6 m	Smart 7.6 m	SP 7.6 m
1	0.5	2	2	2	0.5
2	1	1	4	1	2
3	2	0.5	1	0.5	1
4	4	4	0.5	4	4

Rank 1 designates the deepest piercing; rank 4, the least deep piercing. The actual penetration depths are not shown.

The possibility of piercing real human skulls is, as occasional case reports have implied in the past, very real. Our results regarding the 7-mm head simulant imply that even the relatively thick occiput may be pierced in real cases.

All ammunition types achieved piercing depths of 5 mm or more in 5-mm heads, but only the XP 7.6 m probes reached a maximum of 4.8 mm when fired at the 7-mm heads. The smart 7.6 m managed to pierce almost 4 mm into the synthetic skull cavity, whereas the other probe types presented piercing depths of less than 3 mm.

There seems to be a certain correlation between the firing distance and the penetration depth; the deepest piercing depths were generally achieved at firing distances of 2 m or less.

There also seems to be a certain influence of the thickness of the skull; although the XP 10.6 m pierced most deeply in 5-mm heads, these probes performed rather poorly compared with XP 7.6 m and smart 7.6 m fired at 7-mm heads. The reason for this is unclear, as the shape of the probe is the same in XP 10.6 m, XP 7.6 m, and the smart 10.6 m and 7.6 m cartridges.

In summary, our results—although based on a too small amount of tests to perform exhausting statistical analyses—imply that (*a*) all tested CEW probes are capable of piercing the synthetic skull and that (*b*) shorter firing distances tend to lead to deeper piercing depths.

The observed piercing depths of the probes would—in real situations—only give rise to tiny injuries of the dura and pia mater, and the superficial cerebral cortex. These lesions should not lead to grievous harm or permanent damage to the brain. However, in the very unlikely but nevertheless possible situation in which a blood vessel, for example, a middle meningeal artery or a bridging vein, is harmed by the probe, a life-threatening epidural hematoma may occur. Furthermore, because the lesion represents an open craniocerebral trauma, there is a slight but nevertheless possible risk of a potentially lethal cerebral infection. The minuscule fragments seen occasionally were so small that further damage to the brain or its covering layers can be excluded beyond reasonable doubt.

CONCLUSIONS

Conducted electrical weapon probes may pierce the human skull, even in the region of the relatively thick occiput, especially when fired at distances of 2 m or less. However, the likelihood of severe, life-threatening harm due to the piercing of the skull by the probes is severe, and that of life-threatening harm due to the piercing of the skull by the probes is probably very small and only to be expected in the very unlikely case of vascular damage with epidural hematoma formation or cerebral infection.

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REFERENCES

1. Zipes DP. TASER electronic control devices can cause cardiac arrest in humans. *Circulation*. 2014;129(1):101–111.
2. Zipes DP. Sudden cardiac arrest and death following application of shocks from a TASER electronic control device. *Circulation*. 2012;125(20): 2417–2422.
3. Kim PJ, Franklin WH. Ventricular fibrillation after stun-gun discharge. *N Engl J Med*. 2005;353(9):958–959.
4. Schwarz ES, Barra M, Liao MM. Successful resuscitation of a patient in asystole after a TASER injury using a hypothermia protocol. *Am J Emerg Med*. 2009;27(4):515.e1–515.e2.
5. Naunheim RS, Treaster M, Aubin C. Ventricular fibrillation in a man shot with a Taser. *Emerg Med J*. 2010;27(8):645–646.
6. Swerdlow CD, Fishbein MC, Chaman L, et al. Presenting rhythm in sudden deaths temporally proximate to discharge of TASER conducted electrical weapons. *Acad Emerg Med*. 2009;16(8):726–739.
7. Vilke GM, DeBard ML, Chan TC, et al. Excited delirium syndrome (ExDS): defining based on a review of the literature. *J Emerg Med*. 2012; 43(5):897–905.
8. Kroll MW, Lakkireddy D, Rahko PS, et al. Ventricular fibrillation risk estimation for conducted electrical weapons: critical convolutions. *Conf Proc IEEE Eng Med Biol Soc*. 2011;2011:271–277.
9. Bozeman WP, Hauda WE2nd, Heck JJ, et al. Safety and injury profile of conducted electrical weapons used by law enforcement officers against criminal suspects. *Ann Emerg Med*. 2009;200953(4):480–489.
10. Kroll MW, Lakkireddy DR, Stone JR, et al. TASER electronic control devices and cardiac arrests: coincidental or causal? *Circulation*. 2014; 129(1):93–100.
11. Jenkins DM Jr., Murray WB, Kennett MJ, et al. The effects of continuous application of the TASER X26 waveform on *Sus scrofa*. *J Forensic Sci*. 2013;58(3):684–692.
12. Brave MA, Lakkireddy DR, Kroll MW, et al. Validity of the small swine model for human electrical safety risks. *Conf Proc IEEE Eng Med Biol Soc*. 2016;2016:2343–2348.
13. Panescu D, Kroll MW, Brave MA. New conducted electrical weapons: thoracic cage shielding effects. *Conf Proc IEEE Eng Med Biol Soc*. 2017; 2017:2191–2196.
14. Jauchem JR, Sherry CJ, Fines DA, et al. Acidosis, lactate, electrolytes, muscle enzymes, and other factors in the blood of *Sus scrofa* following repeated TASER® exposures. *Forensic Sci Int*. 2006;161:20–30.
15. Jauchem JR, Cook MC, Beason CW. Blood factors of *Sus scrofa* following a series of three TASER electronic control device exposures. *Forensic Sci Int*. 2008;175:166–170.
16. Dawes DM, Ho JD, Sweeney JD, et al. The effect of an electronic control device on muscle injury as determined by creatine kinase enzyme. *Forensic Sci Med Pathol*. 2011;7:3–8.
17. Becour B. Conducted electrical weapons or stun guns: a review of 46 cases examined in casualty. *Am J Forensic Med Pathol*. 2013;34:142–146.
18. Kroll MW, Adamec J, Wetli CV, et al. Fatal traumatic brain injury with electrical weapon falls. *J Forensic Leg Med*. 2016;43:12–19.

19. Clarke C, Andrews SP. The ignitability of petrol vapours and potential for vapour phase explosion by use of TASER® law enforcement electronic control device. *Sci Justice*. 2014;54(6):412–420.

20. Kroll MW, Ritter MB, Williams HE. Fatal and non-fatal burn injuries with electrical weapons and explosive fumes. *J Forensic Leg Med*. 2017; 50:6–11.

21. Jey A, Hull P, Kravchuk V, et al. Emergent diagnosis and management of TASER penetrating ocular injury. *Am J Emerg Med*. 2016;34(8):1740.e3–1740.e5.

22. Chen SL, Richard CK, Murthy RC, et al. Perforating ocular injury by Taser. *Clin Exp Ophthalmol*. 2006;34(4):378–380.

23. Han JS, Chopra A, Carr D. Ophthalmic injuries from a TASER. *CJEM*. 2009;11(1):90–93.

24. Park KH, Kim WJ, Kang YJ, et al. A case of penetrating eye injury induced by Taser gun. *J Kor Soc Emerg Med*. 2009;20(5):590–592.

25. Teymoorian S, San Filippo AN, Poulose AK, et al. Perforating globe injury from Taser trauma. *Ophthal Plast Reconstr Surg*. 2010;26(4):306–308.

26. Li JY, Hamill MB. Catastrophic globe disruption as a result of a TASER injury. *J Emerg Med*. 2013;44(1):65–67.

27. Rafailov L, Temnogorod J, Tsai FF, et al. Impaled orbital TASER probe injury requiring primary enucleation. *Ophthal Plast Reconstr Surg*. 2017; 33(3S Suppl 1):S176–S177.

28. Cahill C, Jardaleza M. Penetrating ocular injury from Taser. *Austin J Clin Ophthalmol*. 2015;2(2):1–2.

29. Kroll MW, Ritter MB, Kennedy EA, et al. Eye injuries from electrical weapon probes: incidents, prevalence, and legal implications. *J Forensic Leg Med*. 2018;55:52–57.

30. Kunz SN, Adamec J, Zinka B, et al. Wound ballistic evaluation of the Taser® XREP ammunition. *Int J Legal Med*. 2013;127:119–126.

31. Lucas SR, McGowan JC, Lam TC, et al. Assessment of the TASER XREP blunt impact and penetration injury potential using cadaveric testing. *J Forensic Sci*. 2013;58:S60–S68.

32. Chandler J, Martin BP, Graham DD Jr. TASER(®) injury to the forehead. *J Emerg Med*. 2013;44(1):e67–e68.

33. Rehman TU, Yonas H, Marinaro J. Intracranial penetration of a TASER dart. *Am J Emerg Med*. 2007;25(6):733.e3–733.e4.

34. Le Blanc-Louvry I, Gricourt C, Touré E, et al. A brain penetration after Taser injury: controversies regarding Taser gun safety. *Forensic Sci Int*. 2012;221(1–3):e7–e11.

35. Moreira-Gonzalez A, Papay FE, Zins JE. Calvarial thickness and its relation to cranial bone harvest. *Plast Reconstr Surg*. 2006;117(6): 1964–1971.

36. Thali MJ, Kneubuehl B, Vock P, et al. High-speed documented experimental gunshot to a skull-brain model and radiologic virtual autopsy. *Am J Forensic Med Pathol*. 2002;23(3):223–228.

37. Thali MJ, Kneubuehl BP, Dirnhofer R, et al. The dynamic development of the muzzle imprint by contact gunshot: high-speed documentation utilizing the "skin-skull-brain model". *Forensic Sci Int*. 2002;127(3):168–173.

38. Thali MJ, Kneubuehl BP, Dirnhofer R. A "skin-skull-brain model" for the biomechanical reconstruction of blunt forces to the human head. *Forensic Sci Int*. 2002;125(2–3):195–200.

39. Thali MJ, Kneubuehl BP, Zollinger U, et al. A study of the morphology of gunshot entrance wounds, in connection with their dynamic creation, utilizing the "skin-skull-brain model". *Forensic Sci Int*. 2002;125(2–3): 190–194.

40. Thali MJ, Kneubuehl BP, Zollinger U, et al. The "skin-skull-brain model": a new instrument for the study of gunshot effects. *Forensic Sci Int*. 2002; 125(2–3):178–189.

41. Thali MJ, Kneubuehl BP, Zollinger U, et al. A high-speed study of the dynamic bullet-body interactions produced by grazing gunshots with full metal jacketed and lead projectiles. *Forensic Sci Int*. 2003;132(2):93–98.

42. Kneubuehl BP. Simulants. In: Kneubuehl BP, Coupland RM, Rothschild MA, et al, eds. *Wound Ballistics. Basics and Applications*. 1st ed. Berlin, eidelberg, New York: Springer; 2011:136–156.